Deflagration-to-Detonation Control by Non-equilibrium Gas Discharges and Its Applications for Pulsed Detonation Engine

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In this work we present experimental investigations of ignition control by nanosecond gas discharge. This type of gas discharge as a source of active particles has a number of advantages: short time of discharge development, good reproducibility of the discharge parameters, spatial homogeneity over a large gas volume. Experiments were performed in different combustible mixtures in a wide range of experimental parameters. Translational gas temperature was within the range of 480-2200 K. Significant decrease of ignition threshold was observed. Numerical modelling of active species production and chemical kinetics in the afterglow has been carried out.

The problem of fast and homogeneous ignition of combustible mixture is extremely pressing. The ignition method proposed in this paper is based on the usage of the nanosecond high-voltage discharge in the form of fast ionisation wave (FIW) as a source of atoms, radicals, excited molecules. Brief review of our papers concerning kinetic approach to this discharge and detailed description of nanosecond technique of registration is given in [1].

In the case of the breakdown by an impulse of tens - hundreds kV with a front rise rate of 1kV/ns and duration of 10-100 ns the high electric fields result in the effective gas excitation, at the same time the gas translation temperature does not essentially change. The non-equilibrium energy release makes it possible to provide the high efficiency of FIW, as an ignition initiator, at relatively low power consumption. Discharge produces moderate amount of active particles, such as O or H

atoms. But even in the case of low dissociation degree 10^{-3}-10^{-4} it influences dramatically on the kinetics in high-temperature system.

The shock wave uses in this problem to prepare the gas mixture at the specified temperature and pressure. Because the gas dynamic times (0.1–10 ms) are significantly more than the characteristic time of gas excitation by the pulsed breakdown (10–100 ns) the gas in the shock wave may be regarded as motionless from the viewpoint of the discharge. The installation to investigate fast homogeneous ignition of supersonic flows (Figure 1) consists of the discharge cell (DC) connected to a shock tube (ShT), the gas evacuation and supply system, the system of discharge initiation, and the instrumentation system. The shock tube made of the stainless steel has a square cross section of 25x25 mm with the 1.6 m working channel length, high pressure cell (HPC) length of 60 cm. Rotary and diffusive pumps provide evacuation of the shock tube working channel and its mating dielectric discharge section.

The system of shock wave parameters monitoring includes the system of incident and reflected shock wave velocity measurements by the schlieren technique and the system of the initial pressure control. Shlieren system consisted of 3 He-Ne lasers is mounted along the shock tube channel at different points and 3 pairs of photodiods with differential analysers (DA); time delay between points 2-1 and 1-3 along the tube was registered by time-delay analysers (TD). From measured initial gas mixture composition, initial pressure and velocity of the shock wave we determined parameters behind the reflected shock wave, that is pressure, gas density and temperature.

The combustion process behind the reflected shock wave was investigated using emission spectroscopy technique. Emission was registered with the use of monochromator MDR-23, photomultiplier FEU-100 and oscilloscope Tektronix TDS3054 in the direction perpendicular to shock tube axis at a distance of 51 mm from the end plate. We controlled OH emission at λ=306.4 nm. Discharge was synchronized with the reflected shock wave coming to the cross-section of observation. We used pulse generator (PG) to synchronize output from the Shlieren system and power supply (PW) for the high voltage generator. Breakdown was organized in a quartz-glass cell

20 cm in length with optical windows output; the end plate of the shock tube served as high-voltage electrode of the discharge system; the electric circuit was closed via grounded stainless steel working channel of the shock tube.

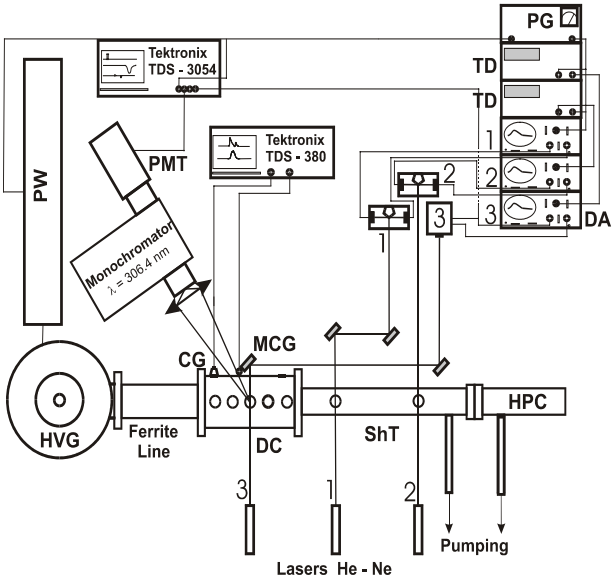

Fig.1. Experimental setup

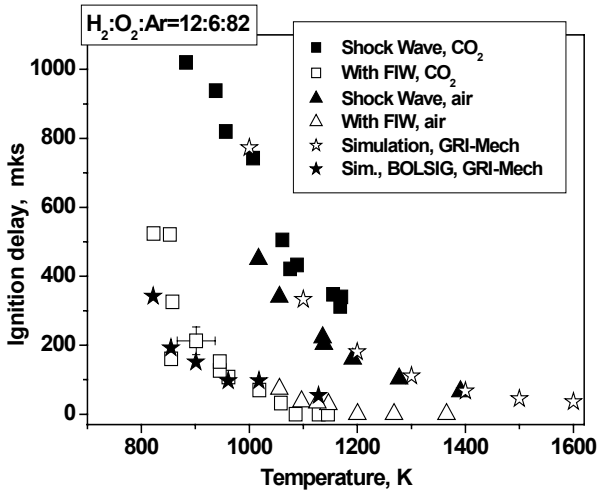

Fig.2. Ignition delay time

The high voltage Marks generator (HVG) provides a voltage range 100-200 kV. Velocity of the ionization wave front is 1-10 cm/ns in dependence on parameters. The system of monitoring of discharge parameters includes magnetic calibrated current gauge (MCG) to control current pulse and capacitance gauge (CG) over the high-voltage electrode to monitor the high-voltage pulse shape and amplitude. Signals were monitored using Tektronix TDS 380 oscilloscope.

Experiments were performed in H_2 and CH_4 mixtures with air or He diluted with Ar or He at initial pressures from 5 to 40 Torr. He, air or CO_2 were used as high-pressure chamber gases. This corresponds to pressures 0.5-1.5 atm behind the reflected shock wave. We used mixtures H_2:O_2:N_2:Ar=6:3:11:80, H_2:O_2:Ar=12:6:82, CH_4: O_2:N_2:Ar=1:4:15:80; H_2:O_2:He=12:6:82. Dilution by Ar or He increased specific heat ratio and molecular weight of the mixture and, so, allowed to reach high temperatures behind the reflected shock wave.

For all investigated mixtures we observed decrease of ignition delay time on 400-600 K, and in H_2:O_2:He mixture we reached threshold of 540 K. We investigated dependence of ignition initiation upon energy release in the discharge in a range of 0.05 J/cm^3. Figure 2 represents dependence of ignition delay time for H_2:O_2:Ar=12:6:82 mixture. Voltage on high voltage electrode was 160 kV, pulse duration was 40 ns. Air or CO_2 (symbols are indicated in the Figure) was used as high-pressure chamber gas. It is clear that in a range of 800-900 K the ignition initiation is possible under the action of discharge only (symbols are marked "with FIW").

In the same Figure results of numerical modeling are represented. To calculate density of O and H atoms we used experimental estimations of electric field value in the discharge and standard BOLSIG solver for the EEDF [2]. To simulate kinetics in the afterglow at high temperatures GRI-Mech 3.0 mechanism was used [3]. It is obvious that correlation between measurements and calculation is good enough and this scheme can be used for estimation of nanosecond discharge efficiency for ignition of combustible mixtures.

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References

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